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Design and Development of Frequency Agile Reflectarray Antenna

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Abstract

This paper presents the design of a frequency reconfigurable reflectarray with concentric circular rings. The PIN diode connected between a phase delay line and the ring produces reconfigured resonances at 16 GHz and 10.4 GHz. The variation in the size of the concentric rings offer a phase change of 356° during the OFF state of the PIN diode. 360° phase variation in the PIN ON condition is achieved by varying the delay line length. A 225-element centre-fed reflectarray antenna is constructed with square geometry. A simulated gain of 23 dBi is obtained with -17 dB side lobe level and -28 dB cross-polarization level at 16 GHz. In the PIN ON condition, a simulated gain of 22 dBi is obtained with -12 dB side lobe level and -28 dB cross polarization level. This reconfigurable reflectarray finds its applications in space research, satellite communication and RADAR.

Keywords: *Reflectarray; Frequency Reconfigurable; PIN diode; Ku-band;X-band*

1. Introduction

Satellite communication plays a vital role in the transmission and reception of information carrying signals with dynamically varying properties. Such dynamic variation ensures security to the information communicated and low loss communication in the desired direction. When compared with the other high gain antennas, reconfiguration of radiation characteristics is done with reduced complexities and power loss using reflectarray antennas. Reconfiguration of operating frequency, radiation pattern, and polarization are attempted by several researchers either by mechanical means, electronic devices, or material characteristics (Narayanasamy et al., 2020). The width of the rectangular slots in the rectangular patches of a reflectarray(Ismail et al.) operating at 10 GHz is varied to create frequency agility. Variation in the radius of semi-circular slots across the width of the rectangular patches also provide change in operating frequency. Thus, the reflectarray produces 323° phase change with these different slot configurations. A similar varying configuration to switch between different operating frequencies is demonstrated using stub connected between the elements in (Rodrigo et al., 2013). The different configurations of these switches and diode offers 270° phase change from 2.33 GHz to 3.54 GHz. Another reflectarray element (Arockiam et al., 2019) is designed by interconnecting four variable size patches using two RF switches and a

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varactor diode to switch between different resonant frequencies. Four reconfigurable elements, such as multi-open loop, cross-loop, open loop patches, and double cross loop are developed to switch between frequencies using a microstrip line as a short in elements. The open circuited condition is when the loop elements are without the microstrip line as a short.

Controlled biasing of the two varactors connected diagonally between the concentric split rings of a reflectarray offers reconfigurable resonant frequencies of 4.2 GHz and 6.5 GHz (Tian et al., 2018). Researchers in (Bhattacharya and Jyoti, 2015) designed a patch with square slot to realize the effect of PIN diode in antenna parameters. The tuning of frequency is realized by changing its effective electrical length. An annular slot rectangular patch antenna is used, and an air gap of 2 mm is used to attach the PIN diode. When the control current is switched "on" and "off" or in the discrete steps, the device is useful for switching, pulse modulating, attenuating, and phase shifting of an RF signal. In (Sun et al., 2014), the proposed antenna, four shorting strips, which are connected to the shorting pins are employed and coupled to the patch instead of directly connected to the patch. An L-probe feed, as a conventional bandwidth enhancement technique, is adopted and coupled to the patch in the top layer of the antenna. The shorting structure is employed as the mechanism to achieve frequency agility. The results show new switching method is much more flexible and compact than the conventional method due to the shorting structure taking very little space. Because three bands are introduced, the switching loss is higher and it is difficult in construction. A similar method is incorporated in (Tian et al., 2019) using a U-slot in the patch which provides a flat input resistance and linear input reactance across a wider bandwidth than the conventional patch antenna. By placing a variable capacitor and an inductor at the antenna input, the impedance matching frequency of the antenna can be varied. The fabricated prototype antenna attains a tunable frequency range from 2.6 to 3.35 GHz. The structure of the antenna is simple and compact. Control circuitry is placed underneath the ground plane which is advantageous in reducing crosstalk from adjacent 9 channels in a multichannel system. A trimmer is introduced to vary the capacitance which can be done by using varactor diodes used on switching stubs.

Thus, several solutions are provided to reconfigure the resonant frequency of the reflectarray antennas. Among those, utilization of PIN diodes for this purpose proves to be a better solution due to its reduced losses, simple integration, and low cost. Hence, in the proposed design, two concentric rings and integrated to a phase delay line through a PIN diode. The switching operation of the PIN diode offers resonances at 10.3 GHz and 16 GHz. The two-layer reflectarray suits the best in the fixed satellite services and earth exploration satellites. The organization of the paper is as follows: In section 2, the unit cell design supported with its reflection characteristics is described. Section 3 provides the description of the reflectarray construction. In section 4, the simulation results of the reflectarray are presented.

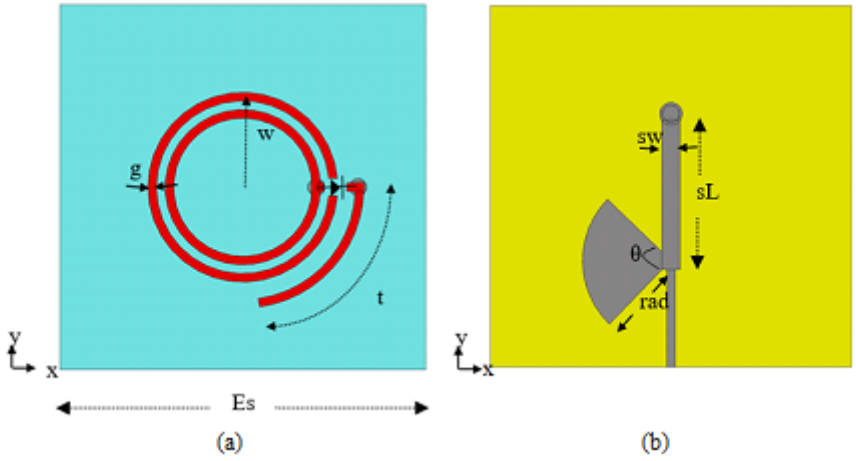

Figure 1. (a) Front view of unit cell and (b) Back view of unit cell

2. Design and Characterization of Refeflectarray Element

The unit cell is developed using concentric circular rings on a Taconic TLY-5 substrate of thickness 1.52 mm. TLY 5 is a low loss substrate with a permittivity of 2.2. Below the ground layer, a lossy substrate Rogers RO4003C acts as the biasing layer. Its permittivity is 4.4. The thickness of the biasing layer is chosen as 1.52 mm. Figure 1 depicts the proposed unit cell structure and the biasing layer. A PIN diode is positioned between the phase delay line and the ring as illustrated in Fig. 1(a). The via is made by etching the substrate over a radius 0.3 mm. The PEC filling of same radius is then made. There is a via pad connected at the end of the via hole that has a radius of 0.4 mm. The quarter-wavelength radial stub is constructed based on the $\lambda/4$ (sL) and also the element size, Es is chosen as 12.7 mm. The ring width and the gap between the rings is maintained as $g = 0.3$ mm.

As shown in Fig. 1(b), the radial stub connected to the quarter-wavelength stub provides impedance matching between the diode and the biasing lines (Huang and Encinar, 2007). Based on the datasheet, the equivalent circuit parameters of the SMV 1340 PIN diodes utilized in the proposed element is chosen as $L = 0.45$nH, $C = 0.16$ pF, and $R = 10\Omega$ in the OFF state. The ON state has 1 ohm resistance while the capacitance and inductance values are the same. The biasing circuit is designed in such a way that the biasing point should be placed at a position with an electric field of nearly zero. This quarter-wavelength microstrip line with an open-ended radial stub is considered to isolate the RF signal from the dc signal. The biasing circuit has a radial-stub connected to the via hole and the other end is grounded, it is used as an LC filter. The value of theta for the stub is taken as 90°.

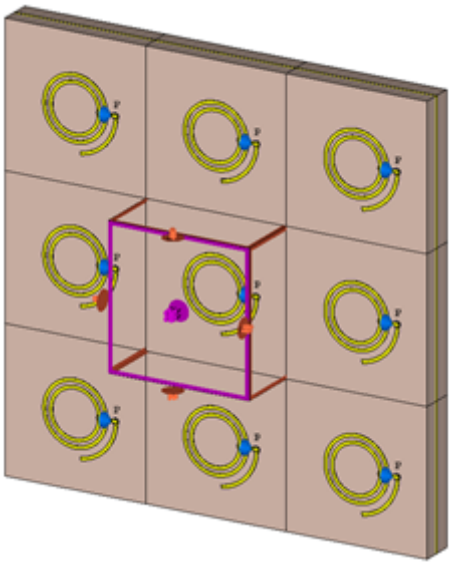

Figure 2. Infinite array model of the proposed element

In the OFF state of the PIN diode, the unit cell resonates at 16 GHz and offers a phase change of 360° through variations in the radius of the concentric rings, w. The unit cell is simulated in frequency domain under unit cell boundary conditions. Figure 2 represents the infinite array model of the proposed element. When the PIN diodes are switched ON, resonance shifts to 10.4 GHz. The surface current distribution as depicted in Fig. 3 explains the response of the element for the two switching states of the PIN diode. The optimized parameter values are specified in Table 1. Figure 4(a) shows the reflection characteristics of the unit cell in the PIN OFF state. 90% reflection is observed in this state. In the ON state of the PIN diode, the length of the phase delay line is varied to offer 360° phase change at 10.4 GHz. Figure 4(b) portrays the phase of the reflection coefficient S_{11} in PIN ON condition.

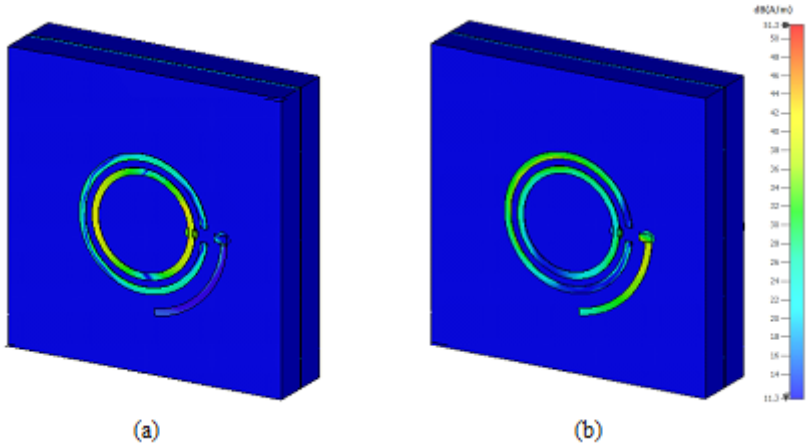

Figure 3. Surface current distribution during (a) PIN OFF (b) PIN ON

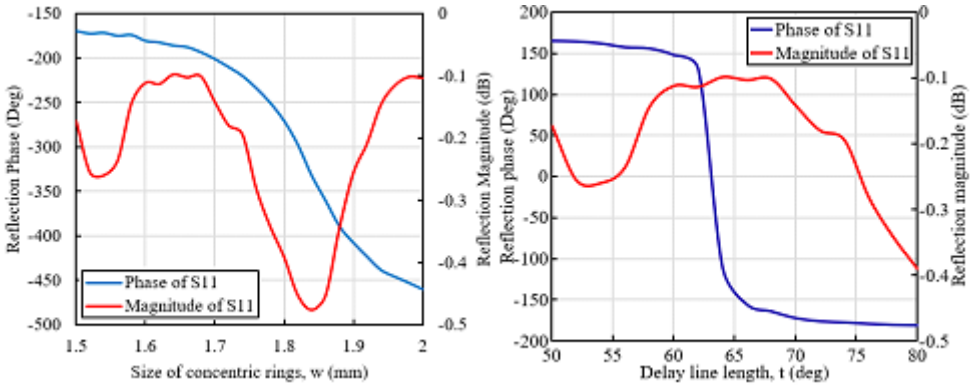

Figure 4. Reflection characteristics at (a) 16 GHz in PIN OFF condition, (b) 10.4 GHz in PIN ON condition

3. Implementation of RRA

Based on the simulated results of the unit cell, a 15×15 reconfigurable reflectarray incorporated with one PIN diode in each element is designed considering a periodicity of 12.7 mm ($0.55\lambda_0$). Thus the 225 elements of the reflectarray are set on a square plane geometry of 191 mm$\times$191 mm size. The required phase shift for all unit cells to be fit in respective locations of the reflectarray is calculated using the phase distribution expression (Huang and Encinar, 2007):

$$\phi_{mn} = k_0(d_i - (x_i \cos\phi_0 + y_i \sin\theta_0) \sin\theta_0 \tag{1}$$

where k_0 is the free space propagation constant, d_i is the distance between the center of the i^{th} element (x_i, y_i) on the plane of reflectarray and the phase center of the feed and (θ_0, φ_0) is the main beam direction.

Figure 5 depicts the phase distribution at 16 GHz obtained using the Equ.1. The required phase shift for each unit cell is determined by comparing the reflection phase curve obtained from CST. Thus, the 225 PIN diodes in the array are used to switch between the different operating frequencies. However, at such a high frequency, the loss and phase shift induced by the diode must be considered carefully. Figure 6 shows the schematic representation of the reconfigurable reflectarray antenna designed. As shown in Fig. 6(b), each end of the open-ended stub is connected to the biasing lines through which the voltage is applied to each PIN diode.

The designed reflectarray is simulated in time domain under open space boundary condition.

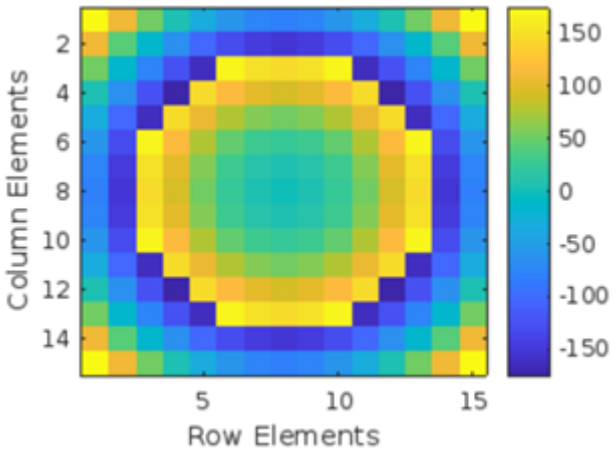

Figure 5. Phase compensation at 16 GHz in PIN OFF condition

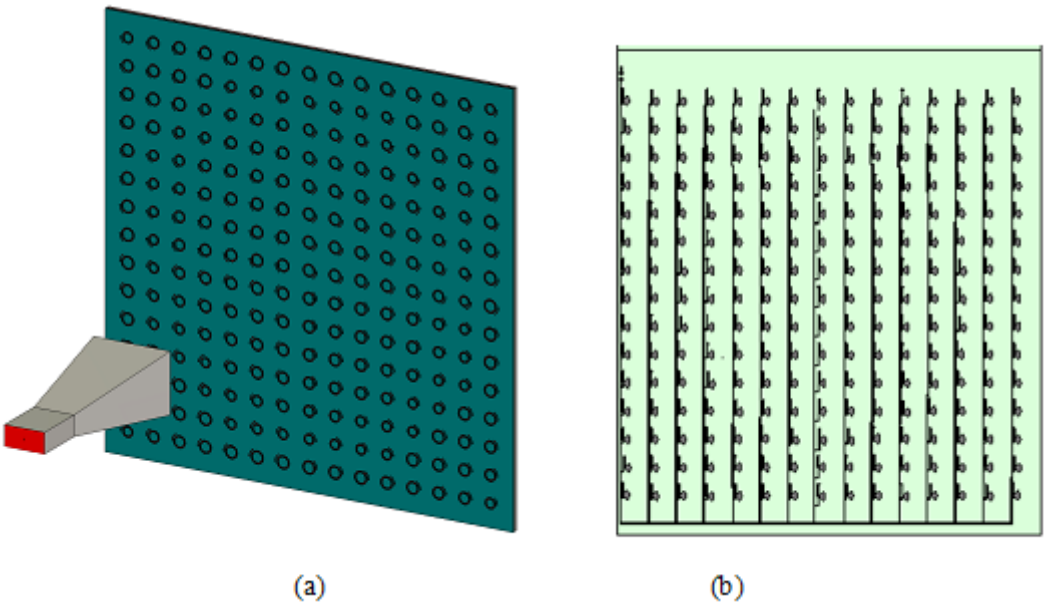

Figure 6. Proposed reflectarray simulation model: (a) front view, (b) back view

Table 1. Parameters of the FRA

Parameters	E_s	w	g	t	sw	sL	rad	θ
Values	12.7	1.5-2 mm	0.3 mm	50-80 deg	0.4 mm	$\lambda_0/4$	1.6 mm	90 deg

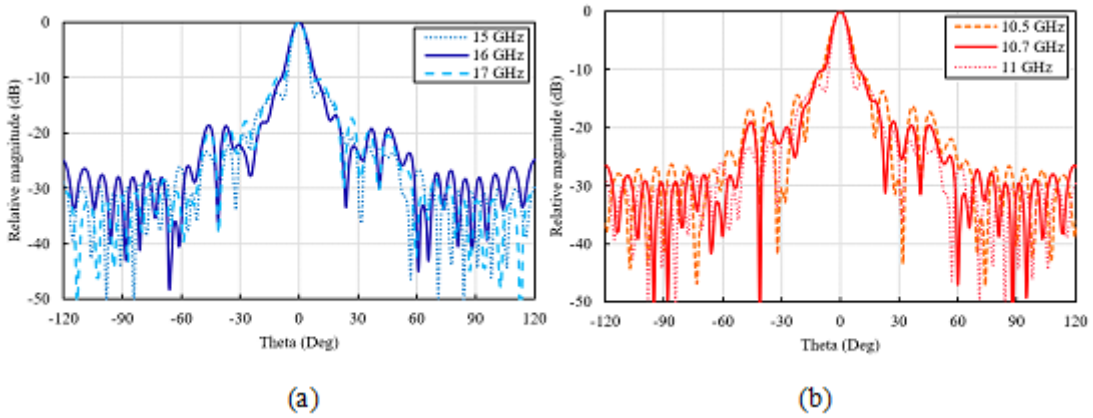

Figure 7. Radiation pattern at different frequencies: (a) PIN OFF condition (b) PIN ON condition

The patterns obtained at different Ku-band frequencies in the PIN OFF state are depicted in Fig. 7(a). The relative magnitude of the pattern at 16 GHz is observed as 23 dB. A side lobe level of -17 dB is observed at this resonant frequency. In the PIN ON condition, the relative magnitude of the pattern is observed as 22 dB at 10.4 GHz. Figure 7(b) illustrates the pattern obtained at different frequencies of X-band. The pattern shows -12 dB of SLL value. Figure 8 shows the cross-polarization levels observed at different Ku-band and X-band frequencies during the OFF and ON states of the PIN diode. A low cross-polarization value less than -28 dB is observed at both states.

Table 2. Comparison of the proposed FRA with the previous works

Parameters	**Current work**	(Rodrigo et al., 2013)	(Arockiam et al., 2019)	(Bhattacharya and Jyoti, 2015)	(Sun et al., 2014)
Operating frequency (GHz)	16/10.4	2.33/3.54	12.32/12.3/30	9.4/8.7	1.559/1.26/1.19
Active device	PIN diode	RF switches, Varactor	NIL (Passive – Stubs)	PIN	NIL (Passive – Shorting Pins)
No. of Active device/Unitcell	1	2 RF switches, 1 Varactor	NIL	1	NIL

Based on the far field results observed at different frequencies within the operating ranges of the proposed reflectarray, the realized gain of the array is plotted against the X-band and Ku-band range of frequencies. Figure 9 shows the gain Vs frequency plot of the reflectarray. A peak gain of 23 dBi and 22 dBi is observed at 16 GHz and 10.4 GHz, respectively, in the PIN OFF and PIN ON states. A 1 dB gain bandwidth from 15.5 GHz to 16.5 GHz is obtained at the PIN OFF state. In the PIN ON state, the 1 dB gain bandwidth is observed from 9.8 GHz to 10.5 GHz.

Table 2 provides the comparison of the features of the proposed FRA with the results discussed

in the literature. From the table, it is inferred that switching between frequencies is obtained in two different bands using reduced number of diodes. With these radiation characteristics and the simple reconfigurable structure, the element be fits fixed satellites and mobile satellites.

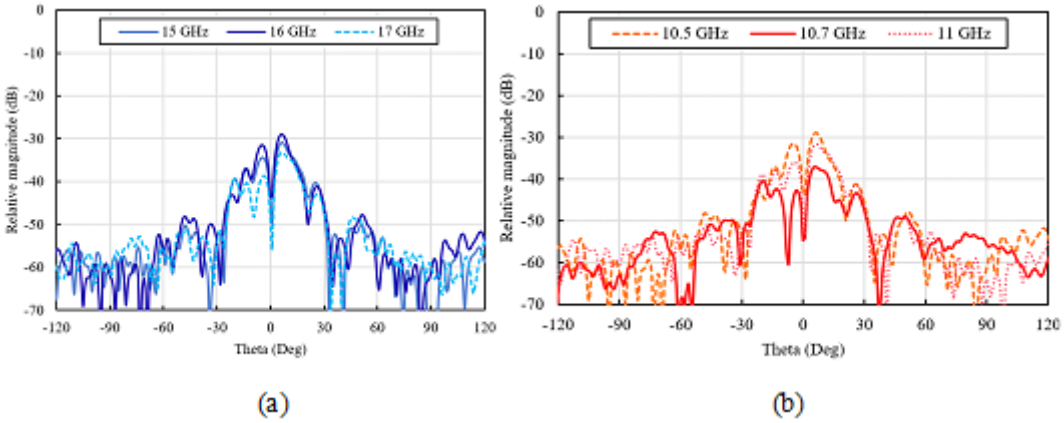

Figure 8. Cross-polarization pattern at different frequencies: (a) PIN OFF condition, (b) PIN ON condition

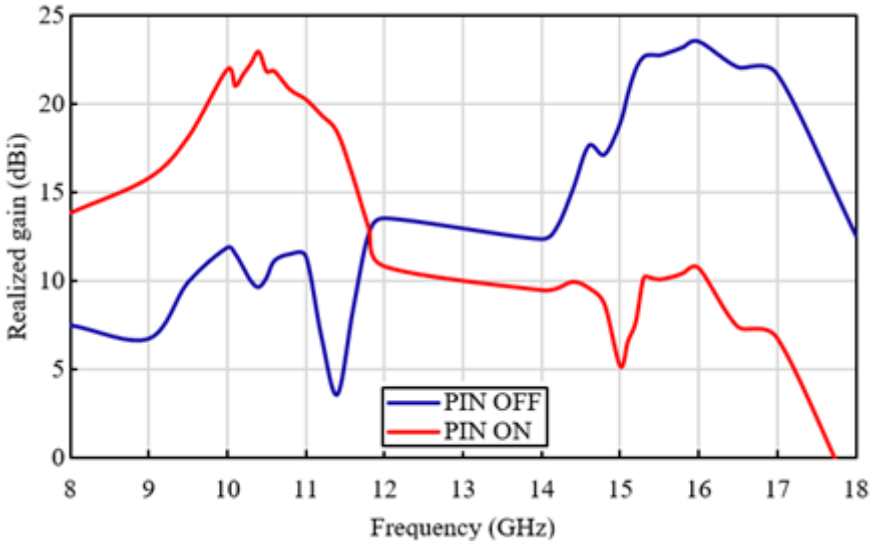

Figure 9. Simulated gain at PIN OFF and PIN ON condition

4. Conclusion

A circular concentric ring with a phase delay line is developed on the Taconic TLY-5 substrate to resonate at two different operating frequencies. Frequency reconfiguration is obtained using the PIN diode connected with the inner ring of each element. The necessary phase shift of 360° is obtained at 16 GHz and 10.4 GHz in the OFF and ON states of the PIN diode. The unit cell was simulated using CST simulation software with the plane wave excitation. Based on the phase curves observed at these frequencies, a 225 element reflectarray is designed and simulated. A Ku-band standard gain pyramidal horn antenna is used for simulation purposes. A peak gain of 23 dBi and 22 dBi is observed at the Ku-band and X-band frequencies, respectively. The designed reflectarray is used for applications, such as military applications, high-resolution imaging radars, remote sensing, and weather monitoring.

References

Arockiam, A. D. T; Gulamnabialsath, M; Vidhyashree, S, and Partibane, B. Studies on the reflection properties of unit cell elements for frequency reconfigurable reflectarray. 2019. doi: 10.1109/ICONSTEM.2019.8918923.

Bhattacharya, A and Jyoti, R. Frequency reconfigurable patch antenna using pin diode at x-band. 2015. doi: 10.1109/ReTIS.2015.7232857.

Huang, J and Encinar, J. A. *Reflectarray Antennas*. 2007. doi: 10.1002/9780470178775.

Ismail, M; Inam, M, and Abdullah, J. Design optimization of reconfigurable reflectarray antenna based on phase agility technique. Citeseer.

Narayanasamy, K; Mohammed, G. N. A; Savarimuthu, K; Sivasamy, R, and Kanagasabai, M. A comprehensive analysis on the state-of-the-art developments in reflectarray, transmitarray, and transmit-reflectarray antennas. *International Journal of RF and Microwave Computer-Aided Engineering*, 30, 2020. ISSN 1099047X. doi: 10.1002/mmce.22272.

Rodrigo, D; Jofre, L, and Perruisseau-Carrier, J. A frequency reconfigurable cell for beam-scanning reflectarrays. 2013. doi: 10.1109/APS.2013.6711492.

Sun, C; Zheng, H; Zhang, L, and Liu, Y. A compact frequency-reconfigurable patch antenna for beidou (compass) navigation system. *IEEE Antennas and Wireless Propagation Letters*, 13, 2014. ISSN 15361225. doi: 10.1109/LAWP.2014.2322754.

Tian, S. C; Zhao, Y. Y, and Li, L. A novel dual-band and dual-polarized reconfigurable reflectarray antenna element. 2018. doi: 10.1109/CSQRWC.2018.8455237.

Tian, S; Liu, H, and Li, L. Dual-band and dual-polarized electrically tunable reconfigurable reflectarray antenna. *Applied Computational Electromagnetics Society Journal*, 34, 2019. ISSN 10544887.